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# REMOVAL OF VOLATILE ORGANIC CONTAMINANTS FROM GROUND WATER

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The three foremost considerations before selecting any treatment scheme are:

(1) The organic quality of the raw water must be thoroughly characterized (i.e., total organic carbon, specific contaminants) as physical and chemical properties provide guidance toward the most cost effective treatment option.
(2) The organic quality of the treated water must be decided, and,
(3) The solution must not substitute the organic problem for microbiological or inorganic deterioration, or increased corrosion potential.

Aeration, adsorption on granular activated carbon, or a combination of these processes are being used to combat ground water problems. In some cases, oxidation or adsorption on synthetic resins may also be effective.

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## ABSTRACT

Because ground water is a source of potable water for millions of people, an economical means of removing volatile organic contaminants is essential. Laboratory, pilot-scale and full-scale studies are being carried out in the United States of America to determine the effect of various treatment processes.

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# Removal of Volatile Organic Contaminants from Ground Water*

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## Introduction

In the United States of America, approximately 100 million ($100 \times 10^6$) people receive their drinking water from ground water sources. These have historically been considered pristine. A recent study, however, has estimated that 15 to 20 percent of the ground water systems across the United States of America contain "man-made" (synthetic) organics (1). Volatile compounds such as trichloroethylene, tetrachloroethylene, and 1,1,1-trichloroethane are the predominant contaminants and the United States Environmental Protection Agency (U.S. EPA) has taken steps to better define the extent of the problem and evaluate potential solutions (2). This paper discusses some of the water treatment processes that have been considered, and in some cases, are being used, to remove or reduce the concentrations of volatile organic contaminants present in some of the ground waters in the United States.

## Treatment Processes

### Precipitation, Filtration, and Oxidation

Other than some incidental volatile losses, conventional water treatment consisting of coagulation, sedimentation, precipitative softening, filtration, and chlorination are ineffective for reducing concentrations of trichloroethylene and related industrial solvents (3). Ozone, a powerful oxidant, has been used in laboratory and pilot-scale studies with limited success for removing cis-1,2-dichloroethylene (4) and tetrachloroethylene (5). Aromatic compounds, such as benzene, can be

*Presented at: International Conference on "Ground Water Contaminant from Organo-Chlorine Compounds of Industrial Origin," Milano, Italy, January 1983.

oxidized by ozone under water treatment conditions (6), but in general, conventional water treatment, and for the most part, oxidation, are not effective for control of ground water contaminants.

Aeration

Air stripping can succesfully lower the concentration of volatile organics in drinking water. Among the several factors that influence aeration effectiveness, perhaps the three most important are:

- the molecular properties of the contaminant(s);
- the ratio of air-to-water applied to the aerator, and;
- the ability to contact a large amount of air with a thin film of water to facilitate transfer of the contaminant into the gaseous phase.

The first factor is best represented by Henry's Law Constant which describes the concentration of the contaminant in the gas and water phases at equilibrium. Experience has shown the efficiency of aeration varies directly with this parameter (7). For example, in Figure 1, 1,2-dichloroethane is more difficult to strip from water than 1,1,1-trichloroethane, which in turn is more difficult to strip than 1,1-dichloroethylene. The other factors listed above are dependent on the type of aerator.

Currently (1982), an estimated 10 to 12 United States utilities are aerating to strip volatile organics from their drinking water. The three principal types of aerators being used are, redwood slat aerators, packed towers, and spray towers. Two additional methods, diffused-air sparging and air-lift pumping, are being evaluated for potential full-scale application. Schematic drawings of these aeration devices are shown in Figure 2.

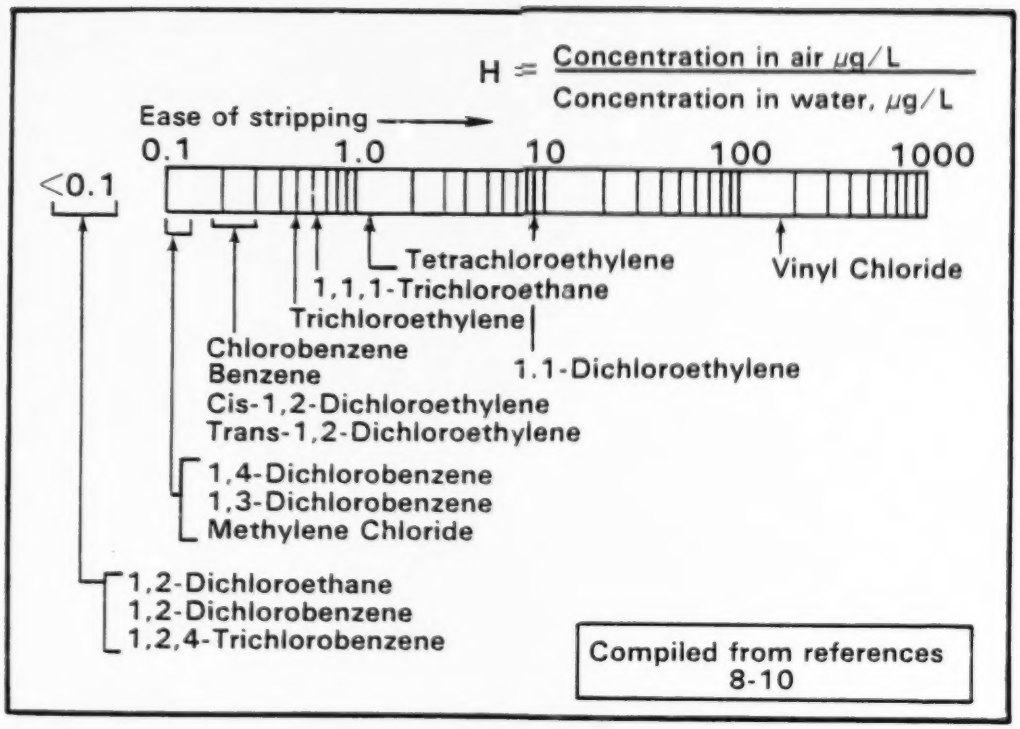


Figure 1. Comparison of Henry's Law Constants for Selected Organics.

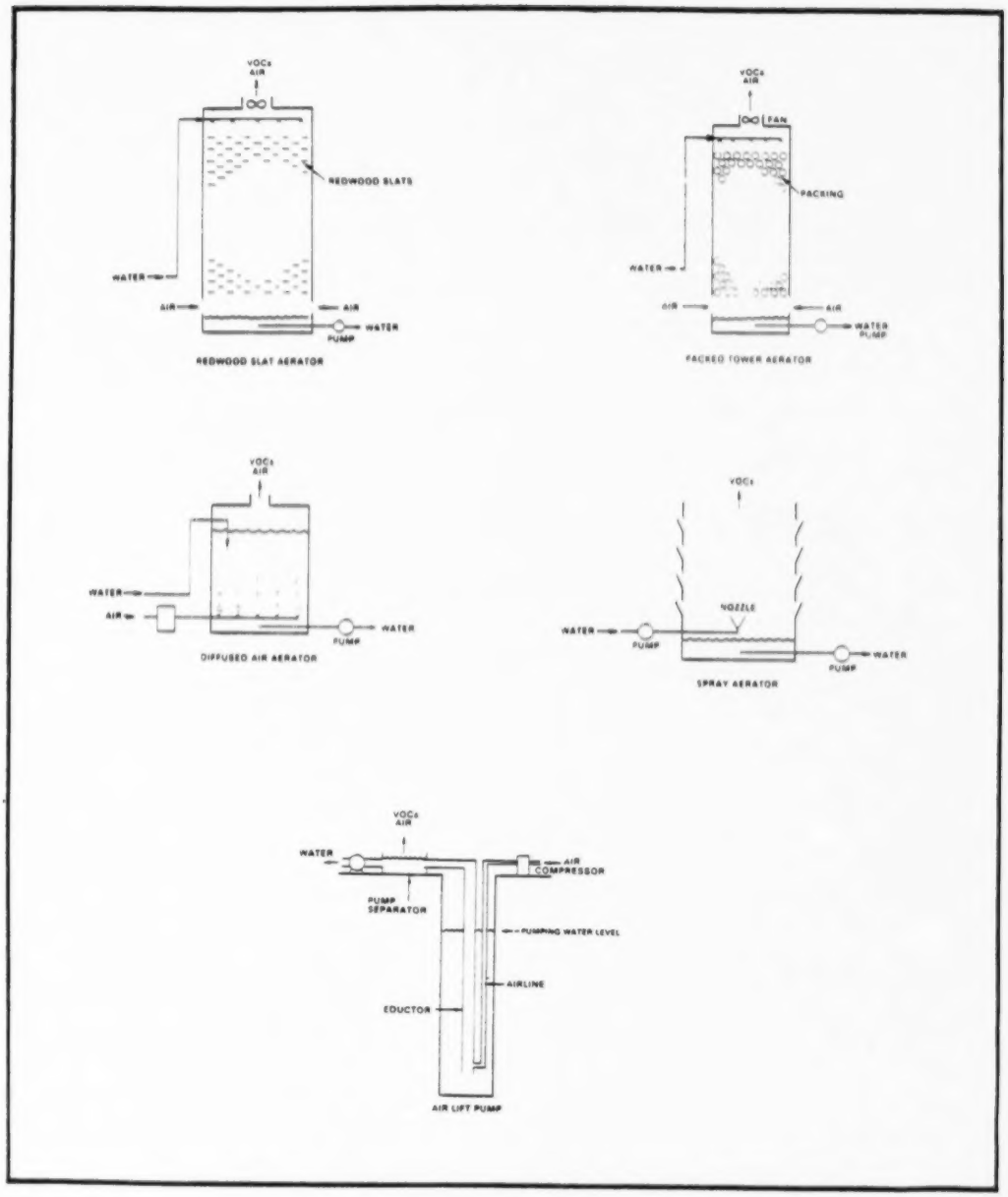


**Figure 2. Aeration Devices Used to Remove Volatile Organic Compounds from Drinking Water.**

Comparative performance data and cost of construction and operation are being gathered on the different types of aerators by the U.S. EPA - Drinking Water Research Division (DWRD). Some of the preliminary findings will be discussed in the following brief overview of each device.

Diffused-Air Aerators

Laboratory studies by U.S.EPA-DWRD in 1977 showed this process was effective for removing industrial solvents "spiked" in distilled water. The following year, a pilot-scale aeration project was started in the state of New Jersey at a contaminated ground water site. The results of this field work have been published (3), but a summary is repeated in Figure 3 to show how mixtures of solvents behaved with the modest air-to-water ratio of 4 to 1. This process is still being evaluated (11), but getting air-to-water ratios above approximately 20 to 1 is difficult. Also as will be shown later, the cost of diffused-air aeration is estimated to be relatively high.

Packed-Tower Aerators

This device consists of a column, 1 to 3 m in diameter and 5 to 10 m in height, that is filled with packing material. This packing can be glass, ceramic, or plastic and is available in numerous geometrical shapes to facilitate the transfer of mass from the aqueous phase to the gas phase. The inside wall of the aeration column has several "redistributors" that force the water over the packing and thus prevent the water from simply running down the walls. The diagram in Figure 2 shows a fan at the top. This is called an "induced draft" packed tower. Perhaps more common is the "forced draft" packed tower where a blower positioned at the bottom of the tower forces air up through the packing. Two excellent references (12,13) are available that describe these devices and show how they can be designed to remove 98 percent or higher of the volatile organic compounds found in ground water.

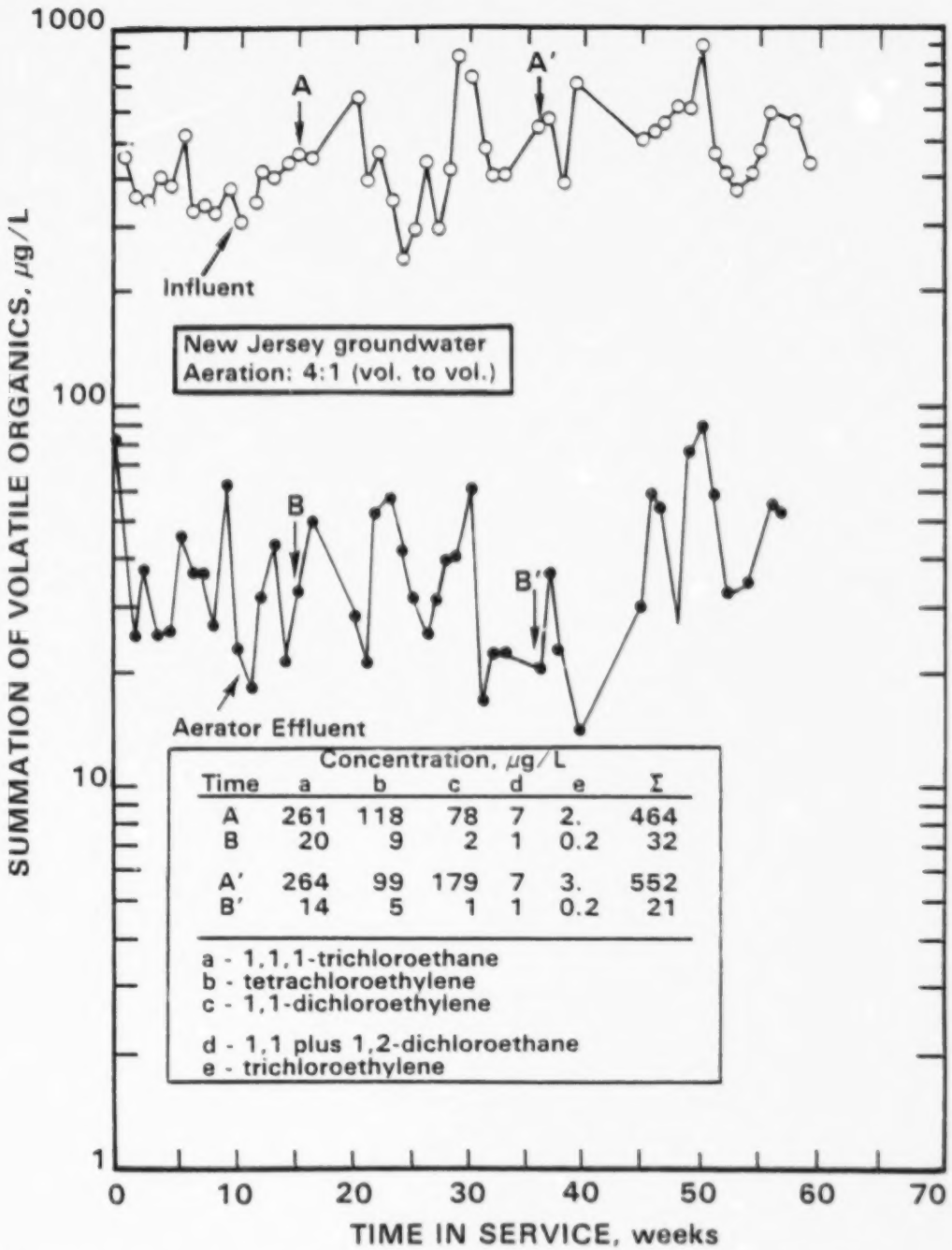


Figure 3. Removal of Volatile Organic Compounds by Aeration (Pilot-Scale Study) (3)

The U.S. EPA - DWRD has two projects on packed-tower aerators. One (14) involves evaluating scale-up from pilot plant data (i.e., how small a unit still produces reliable design data?) and the other (15) concerns the topic of secondary effects from aeration. These secondary effects will be defined later.

Redwood Slat Aerators

These devices are fundamentally cooling towers, but have been used to remove iron and manganese, or hydrogen sulfide from drinking water. They also can remove a high percentage (20 to 90 percent) of volatile organics (16).

Spray Aerators

Spray aerators are being used in the State of Florida at a drinking water source containing trichloroethylene and related industrial solvents. In that installation, the water is pumped through four aerators in series. The removal efficiency for this operation is reported to be greater than 99 percent (17).

As a temporary measure while a packed tower aerator was being designed, one United States water utility faced with industrial solvent contamination, suspended a 10 cm diameter pipe grid inside the top of one of their above-ground steel storage reservoirs. This grid had some spray nozzles but it also had a pattern of slits cut with a welding torch. The storage reservoir hydraulically floated on the distribution system, so a separate pump was installed to recirculate the stored water continuously through the spray grid. This energy intense arrangement reportedly reduced trichloroethylene concentrations by 50 to 70 percent.

Air Lift Pumps

Early in the 20th century, air-lift pumps were commonly used in the United States. These are simple devices with only two pipes in the well. One pipe introduces compressed air into the open bottom of the other pipe, called an eductor (see Figure 2). In the eductor, air mixes with water. The mixture, being of lighter density than the surrounding water will rise to the surface. The air is separated before the water is pumped into the distribution system. Because of poor pumping efficiency, typically 35 percent, they fell into disuse with the introduction of submersible pumps.

In 1980, a water utility in the state of Pennsylvania with a solvent contaminated ground water began studies with air-lift pumps. Although it may be more expensive to pump with an air lift, using the well as a reaction vessel may offset the costs of having to invest in an above-ground aerator. The utility's preliminary tests showed 40 to 70 percent removal of trichloroethylene using an air-lift pump and U.S. EPA-DWRD is currently participating in a study to examine in-well aeration in detail (18). In this study, air sparging in the well in conjunction with a submersible pump will also be investigated. Preliminary air sparging tests showed 80 percent removal of trichloroethylene.

Aeration Summary

Several observations can be made about the aeration process.

- Because mixtures of solvents exist in contaminated water and even though the effectiveness of the process varies for each solvent, aerating to remove one specific contaminant will also reduce concentrations of the others.
- The percent removal of a contaminant is very constant, for a given set of operating conditions, and does not vary with the influent concentration.

- The temperature of ground water is consistently around 13°C. Even when subjected to extremely cold air during the winter, the temperature of the aerated water drops but a fraction of a degree, thus these units can be operated in cold weather climates. Some housing, however, is probably prudent to protect the device from freezing in the event of a pump failure (12).

Questions have been raised concerning the secondary effects of aeration. These include potential air quality problems created by exhaust gases from the aerator, and the potential for water quality deterioration from airborne particulates, oxidized inorganics, instability resulting in corrosion, and biological growth in the aeration device. Although they are not thought to be significant problems, U.S. EPA-DWRD is investigating these secondary effects to understand more fully the aeration process (15).

Adsorption

As with aeration, the effectiveness of adsorption varies depending largely on:

- type of adsorbent (resin or activated carbon)
- contact or residence time
- concentration and nature of the contaminants
- background concentration of organic carbon

In 1976, the Rohm and Haas Company introduced an experimental synthetic resin called Ambersorb XE-340*. This material was designed specifically for removing low molecular weight halogenated compounds because at that time chloroform and other trihalomethanes were the topic of intense research in the United States. Over the past 5 years, the U.S. EPA-DWRD has been involved in several pilot-scale experimental trials using XE-340 resin at solvent contaminated ground water sites (3). One project in New York State (11) focused on

*Mention of a commercial product does not constitute acceptance or endorsement by U.S. EPA.

in-place steam regeneration of the resin. Although this material looked very promising because of its high adsorption capacity, the manufacturer recently (1982) announced that XE-340 would not be commercially produced. The future of resins for controlling ground water contaminants is therefore questionable.

Figure 4, a compilation of data from several laboratory studies with activated carbon (19-21), illustrates two important points: one, the organic compounds found in ground water cover a wide range of adsorption capacities, and two, the adsorption capacity varies directly with the concentration of the organic.

Data collected from a U.S.EPA-DWRD pilot scale adsorption study (part of the diffused-air project mentioned earlier) are summarized in Figure 5. For approximately 30 weeks (17,000 bed volumes) the contaminants were removed to below detection (0.1 micrograms per liter, ug/L) by the activated carbon. When breakthrough occurred, the principal organic compounds were the chloroethanes, which is consistent with the order of adsorption capacities given by the isotherm data in Figure 4. Note, at point B" the 1,1,1-trichloroethane concentration in the effluent slightly exceeded the influent indicating desorption was occurring. This is more apparent on Figure 6, where 1,1,1-trichloroethane data are presented alone. After the activated carbon was exhausted for removing this solvent (around week 55), more contaminant often appeared in the treated water than in the untreated water. This might be the result of equilibrium or of displacement by more competitive organic chemicals.

Another important point is that adsorption can be affected by the amount of background organic carbon, generally measured as total organic carbon. Investigators (21) have shown a high background

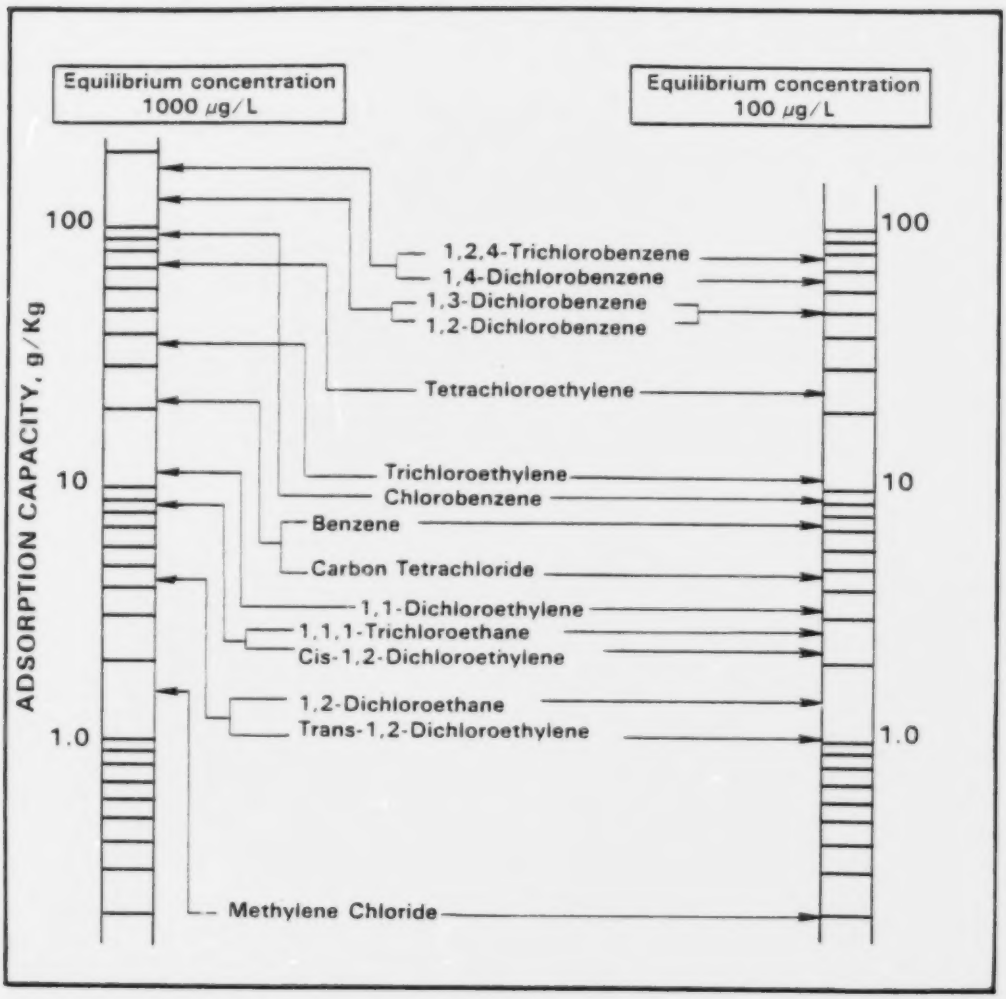


Figure 4. Comparison of Isotherm Adsorption Capacities on Activated Carbon (19-21)

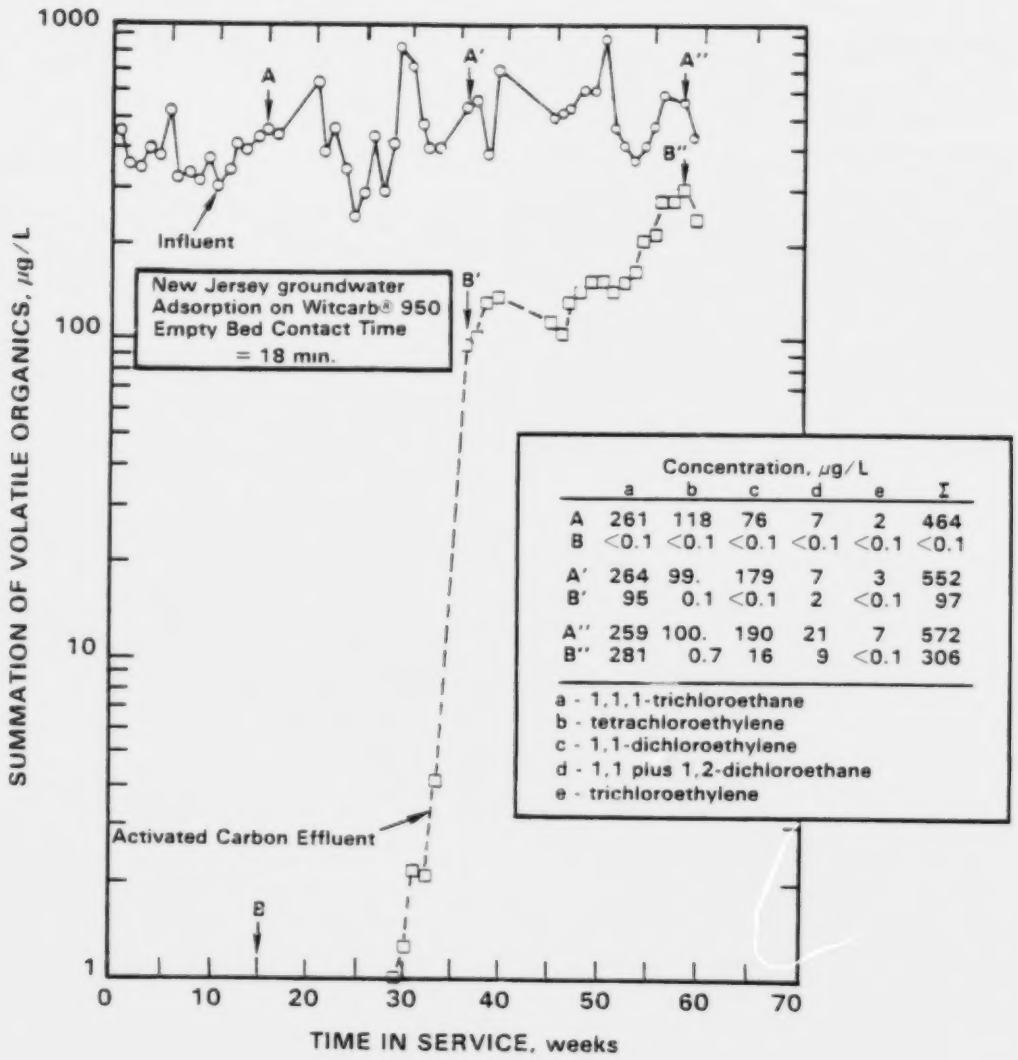


Figure 5. Removal of Volatile Organic Compounds by Adsorption on Granular Activated Carbon (Pilot-Scale Study) (3)

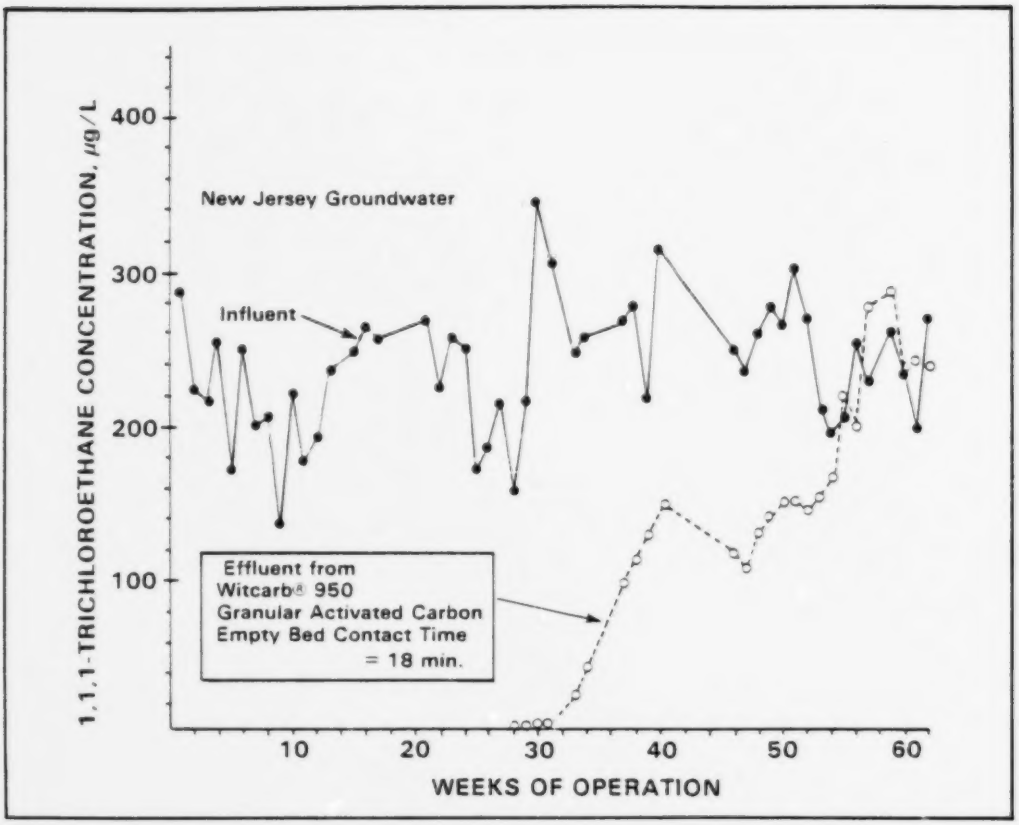


Figure 6. Removal of 1,1,1-Trichloroethane on Granular Activated Carbon (Pilot-Scale Study) (3)

organic content (i.e., over 1.5 to 2 milligrams per liter) can result in lower than expected adsorption capacities. Competitive adsorption and the influence of high concentrations of background organic carbon are recognized, but not well understood.

The manufacturers of activated carbon in the United States are beginning to offer adsorption services and 5 or 6 water utilities are using this treatment option. (This service is more widely used on industrial wastewaters.) In general, the service consists of characterizing the water, sizing, constructing, and installing the adsorption vessels, and replacing the granular activated carbon with virgin material when the concentration of a contaminant exceeds a predetermined effluent quality. The exhausted adsorbent is returned to the manufacture, regenerated, and resold for industrial uses. The adsorbers are normally operated in series with empty bed contact times typically ranging from 14 to 18 minutes. The time of operation varies (usually designed to operate 12 or more months) because no uniform agreement exists on acceptable effluent concentrations.

To more fully utilize the capacity of granular activated carbon, adsorbers are usually operated in series in a manner that allows each adsorption vessel to remain on-line until the activated carbon is fully exhausted before it is replaced. This two-stage, series operation and the steps involved are simplified in Figure 7. As contrasted to operating adsorbers in parallel, the series operation can utilize a significantly larger portion of the adsorbent. For example, using the breakthrough curve in Figure 5 and assuming an effluent target concentration of 10 to 50 ug/L, as much as 30 percent additional utilization of the activated carbon might be expected if a

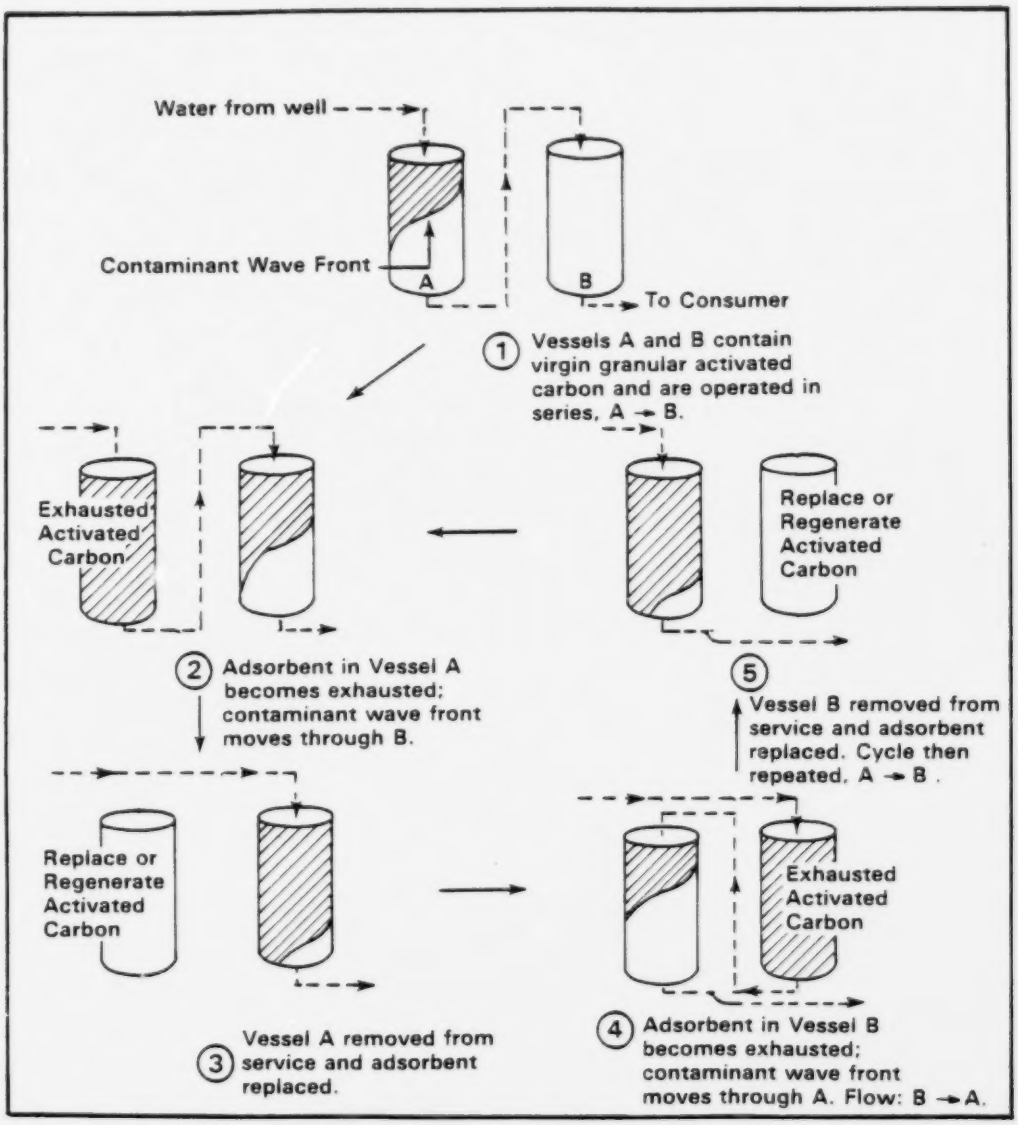
Water from well
Contaminant Wave Front
A
B
To Consumer
1 Vessels A and B contain virgin granular activated carbon and are operated in series, A → B.
Exhausted Activated Carbon
Replace or Regenerate Activated Carbon
2 Adsorbent in Vessel A becomes exhausted; contaminant wave front moves through B.
5 Vessel B removed from service and adsorbent replaced. Cycle then repeated. A → B.
Replace or Regenerate Activated Carbon
Exhausted Activated Carbon
3 Vessel A removed from service and adsorbent replaced.
4 Adsorbent in Vessel B becomes exhausted; contaminant wave front moves through A. Flow: B → A.

Figure 7. Two-Stage Series Operation to maximize Use of Activated Carbon.

two-stage, series operation was used.

Home Treatment Units

In some circumstances, such as where a central treatment system is not feasible, or in emergency situations, home treatment units utilizing activated carbon adsorption have been successful (22). The U.S.EPA-DWRD has contracted with the National Sanitation Foundation (23) to evaluate the surveillance problems related to providing the maintenance and attention these units require.

Combination of Treatment Processes

Two or three water utilites in America have preceded adsorption with aeration and have found this combination to be extremely effective for producing a water with volatile organic concentrations below a detection limit of 0.1 ug/L. The aeration step reduces the organic load to the adsorbent and may remove compounds competing for adsorption sites.

Relative Costs of Treatment

Cost estimates vary significantly because each process has a spectrum of effectiveness. From the available estimates (24,25), some generalizations can by made on relative costs and are shown in Table 1. Packed tower aeration is considerably less expensive than diffused-air aeration or adsorption on activated carbon. The cost of packed-tower aerations ranges from 0.03 to 0.1 United States dollars per cubic meter of water depending on the size of the aerator. Similar cost comparisons are not available for the other aeration devices. Note, the cost of aeration does not include any expenditures that may result from secondary effects.

Table 1. Relative Costs of Treatment (24,25)

| Process | Cost |
|---|---|
| Packed Tower Aeration | 1 |
| Diffused Air Aeration | 2-3 |
| Granular Activated Carbon Adsorption | 2-3 |

Summary

Organic solvents of industrial origin occur in ground water supplies. The seriousness of drinking water contamination is a topic of concern to U.S. EPA (2) and four workshops* have been conducted regionally to discuss not only the occurrence data, but also the treatment information and the potential for associated health effects. Some states have independently developed "action levels" for the volatile organic compounds in drinking water and a few water utilities have installed treatment.

Aeration, adsorption on granular activated carbon, or a combination of these processes are all being used. Because aeration is the least expensive alternative, it will likely be the first process considered by a consulting engineer unless difficult-to-strip compounds are predominant in the water. The secondary effects of aeration are therefore being closely evaluated by U.S.EPA. In particular, the aerator exhaust gases may have to be controlled by passage through an adsorbent. Additionally, the increased dissolved oxygen in the drinking water after aeration may prove detrimental to pipes in a distribution system. Understanding the potential problems created by suggested solutions are part of the on-going water treatment research in the United States.

*"Workshop on Volatile Organic Chemicals" conducted by the American Water Works Association Research Foundation and the U.S. EPA in Chicago, IL (June 8-9), Reno, NV (June 29-30), Philadelphia, PA (July 20-21), and Biloxi, MS (August 18-19) 1982).

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